Importance of Limiting Soil Pressure on Pile Responses (Part 2 of 3)

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This article is a continuation of the author's contribution published in the preceding issue of JURUTERA. It forms the second of three parts that constitutes the full article.

FIGURE 1 shows the sketch of the centrifuge package that consists of the centrifuge strong-box and various miniature instruments to measure soil, pile and pore water pressure responses. In order to study the phenomenon of limiting soil pressure, the centrifuge model set-up and model ground preparation have been described in detail by Ong *et al.* (2006) and Leung *et al.* (2006). In summary, the instrumented model pile has a prototype width of 630mm at 50g and the distance of pile from the model retaining wall varies accordingly. The model retaining wall is simulated using a 3-mm (prototype 150-mm) thick aluminum plate with length of 160mm (8m). The equivalent prototype bending rigidity, EI, of the model pile and wall are approximately 2.2 x 105 kNm^2 (equivalent to a 600-mm diameter Grade 35 bored pile or a 610-mm diameter steel pipe pile with 12.7mm wall thickness) and 24 x 103 kNm^2/m (equivalent to a FSP IIA sheet pile), respectively. The in-flight excavation is carried out until failure of the wall occurs at about 1.8m.

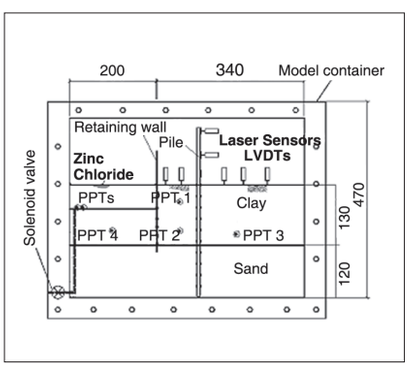

Figure 1: Centrifuge model set-up to be subjected to acceleration of 50 times of Earth's gravity (50-g) (Model dimensions in mm)

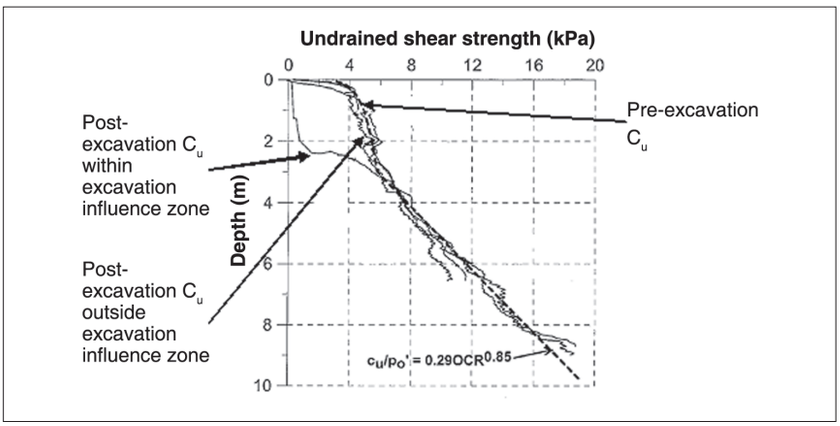

Figure 2: Clay undrained shear strength profiles

To evaluate the undrained shear strength, cu of the clay, T-bar penetrometer tests (Stewart and Randolph, 1991) were performed in-flight within and outside the excavation influence zone. Figure 2 shows that there is a significant reduction in the cu within the excavation influence zone, most likely due to stress relief. On the other hand, there is no noticeable reduction in the cu outside the zone of influence.

High-resolution photographs were taken during various excavation stages as shown in Figure 3. It is evident that tension cracks have developed when excavation depth exceeds 1.0m. These cracks cause the loss of contact of clay in front of the pile.

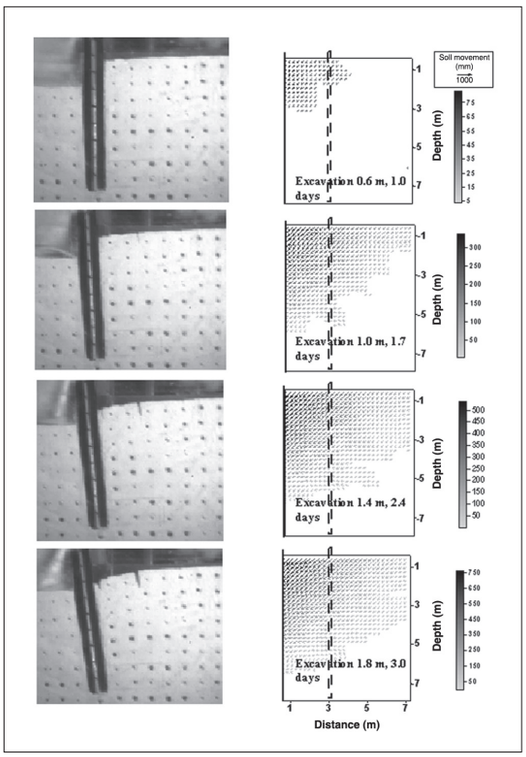

Figure 3: High-resolution photographs showing various excavation stages (Note that pile is located within the excavation influence zone)

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Figure 4 shows the plan view of the extent of deformed soil around the pile after the testing.

DEVELOPING THE UNDERSTANDING OF LIMITING SOIL PRESSURE

Limiting soil pressure is only mobilised when the soil body fails and subsequently causes a large-strain soil movement, reminiscent of landslide, debris flow or riverbank slope movement. The numerical method developed by **Chow and Yong (1996)** is used to back-analyse the responses of the pile. This method is currently being developed into a software package to operate as a Windows-based application, a collaborative effort between the author and Prof. Y.K. Chow of National University of Singapore (NUS).

The concept of analysis is based on finite element method where the pile is represented by beam elements and the soil is idealised using the modulus of subgrade reaction. The non-linearity of the soil behaviour can be incorporated to an extent by limiting the soil pressure that can act on the pile. The numerical analysis requires the knowledge of the pile flexural rigidity (EI), the distribution of lateral soil stiffness (K_h) with depth, the limiting soil pressure (p_y) that acts on the pile and the lateral soil movements.

For clay, the distribution of the lateral soil stiffness with depth, K_h is assumed to approximate the Young's modulus of the soil, E_s:

$$K_h \sim E_s \qquad (1)$$

where E_s = 200-350c_u. For pile in clay, a simplified distribution of soil resistance or limiting pressure, p_y, with a maximum value of 9c_u is initially suggested using the concept of a laterally loaded pile for convenience, as per **Poulos and Davis (1980)**:

$$p_y = 2(1+z/d)c_u \leq 9 \qquad (2)$$

where z is depth and d is pile diameter. However, the limiting pressure of 9c_u may not be applicable as shown in the subsequent analysis as the pile is subjected to lateral soil movement during excavation, which renders it a passive pile.

The last of this 3-part article describes the importance of limiting soil pressure in the design of piles when subjected to large-strain soil deformation. ■

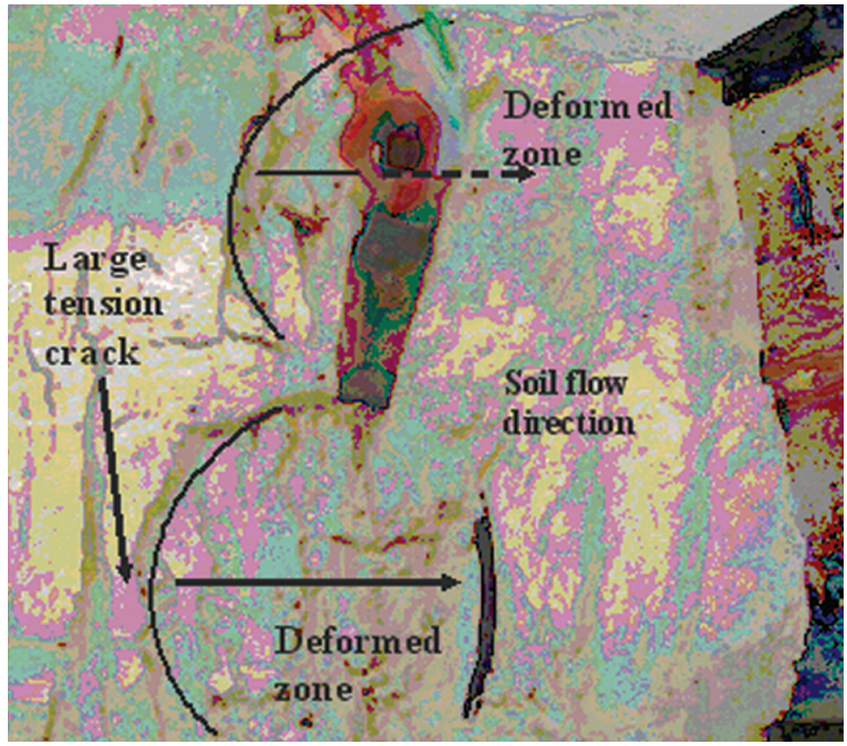

Figure 4: Plan view of deformed soil around pile after excavation

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